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Attorney's Docket No. PP00-4 **PATENT APPLICATION**

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: Thompson

Serial No.: 09/825,636 **Group No.:** 2683

Filed: April 4, 2001 **Examiner:** Miller, Brandon J.

For: MULTI-BEAM ANTENNA WIRELESS NETWORK SYSTEM

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION UNDER 37 CFR 1.131

Dear Sir:

I, Scott D. Thompson of 965 Grace Street, State College, PA 16801, declare that:

I hold the degree of BSEE from Pennsylvania State University, University Park PA (1981) and the degree from MSEE from Southern Methodist University, Dallas TX (1985)

I am a named inventor in the above-identified patent application.

That the conception of using an Ethernet switch as part of the hub in the above-identified patent application was prior to the effective date of the Sydor patent reference coupled with due diligence from prior to the reference date to the filing date of the application. Attached as evidence to this declaration is a confidential proposal discussing the Ethernet switch as part of the hub, dated on August 3, 1998. The proposal disclosure shows conception of the invention prior to effective date of May 5, 1999 for the Sydor patent reference.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patents issuing thereon.

11.22.04
Date

Scott D. Thompson

APPENDIX A

U.S. DEPARTMENT OF DEFENSE

SMALL BUSINESS INNOVATION RESEARCH (SBIR) PROGRAM
PROPOSAL COVER SHEET

Failure to fill in all appropriate spaces may cause your proposal to be disqualified

TOPIC NUMBER: A98-038

PROPOSAL TITLE: Intelligent Access Hub Technology

FIRM NAME: Anntron, Inc.

MAIL ADDRESS: Fred C. Thompson, 1440 Willowbrook Dr.

CITY: Boalsburg STATE: PA ZIP: 16827

PROPOSED COST: $ 68,425 PHASE I OR II: I PROPOSAL PROPOSED DURATION: 6 IN MONTHS

BUSINESS CERTIFICATION:

	YES	NO
Are you a small business as described in paragraph 2.2?	X	
Are you a socially and economically disadvantaged business as defined in paragraph 2.3? (Collected for statistical purposes only)		X
Are you a woman-owned small business as described in paragraph 2.4? (Collected for statistical purposes only)		X
Have you submitted proposals or received awards containing a significant amount of essentially equivalent work under other DoD or federal program solicitations? If yes, list the name(s) of the agency or DoD component, submission date, and Topic Number in the spaces below.		X

- Number of employees including all affiliates (average for preceding 12 months): 2

PROJECT MANAGER/PRINCIPAL INVESTIGATOR	CORPORATE OFFICIAL (BUSINESS)
NAME: Scott Thompson	NAME: Fred C.Thompson
TITLE: Staff Engineer	TITLE: President
TELEPHONE: (814) 235-1586	TELEPHONE: (814) 466-7818

For any purpose other than to evaluate the proposal, this data except Appendix A and B shall not be disclosed outside the Government and shall not be duplicated, used or disclosed in whole or in part, provided that if a contract is awarded to this proposer as a result of or in connection with the submission of this data, the Government shall have the right to duplicate, use or disclose the data to the extent provided in the funding agreement. This restriction does not limit the Government's right to use information contained in the data if it is obtained from another source without restriction. The data subject to this restriction is contained on the pages of the proposal listed on the line below.

PROPRIETARY INFORMATION:

Before signing below, please read the cautionary note at Section 3.7

Scott D. Thompson 8/3/98 Fred C. Thompson 8/3/98

SIGNATURE OF PRINCIPAL INVESTIGATOR DATE SIGNATURE OF CORPORATE BUSINESS OFFICIAL DATE

Nothing on this page is classified or proprietary information/data

APPENDIX B

U.S. DEPARTMENT OF DEFENSE

SMALL BUSINESS INNOVATION RESEARCH (SBIR) PROGRAM
PROJECT SUMMARY

Failure to fill in all appropriate spaces may cause your proposal to be disqualified

TOPIC NUMBER: A98-038

PROPOSAL TITLE: Intelligent Access Hub Technology

FIRM NAME: Anntron, Inc.

PHASE I or II PROPOSAL: I

Technical Abstract (Limit your abstract to 200 words with no classified or proprietary information/data.)

An Intelligent Access Hub Concept for Wireless Wide Area Networks (W-WANs) is described. This Intelligent Access Hub network is a high capacity multimedia, rapidly deployable architecture which nominally supports 10 Mb/s data rates from the ATM backbone to each fixed or roaming Information Kiosk (IK). The concept exploits smart directive antennas which emphasize signal reception from the desired IK and de-emphasize interference from other directions in a process called spatial filtering. Spatial filtering may be used to resolve the signal from distinct IKs providing for Spatial Division Multiple Access (SDMA). The fundamental limitation to SDMA is Signal to Interference Ratio (SIR). A unique solution to mitigate the SIR is proposed using a smart beamformer and adaptation of radio bridge protocols. Transmission in directive beams with minimum power provides inherent Anti-Jam and Low Probability of Intercept (AJ/LPI) properties. The design is COTS richto reduce cost, weight, and risk of the system. The architecture is realized in the Unlicensed National Information Infrastructure (U-NII) band for low cost, unlicensed implementation, but the concept is applicable to other frequency bands. The architecture has immense commercial appeal as a cost effective alternative to paying wireline leases for provision of Wide Area Networks.

Anticipated Benefits/Potential Commercial Applications of the Research or Development.

Wireless WANs create a new class of service for commercial data service providers. The wireless medium eliminates the dependence on the installed infrastructure and incumbent pricing. A wireless WAN is rapidly deployable, scaleable, and inexpensive relative to the public wireline infrastructure

List a maximum of 8 Key Words or short (2-3 word) phrases that describe the Project.

Beamformer	Multimedia
Low Probability of Intercept	Smart Antennas
Spatial Division Multiple Access	U-NII Band
Wireless Wide Area Network	Anti-Jam

Nothing on this page is classified or proprietary information/data

Intelligent Access Hub Technology

Table of Contents

1. Identification of Problem and Opportunity

1.1 Background

It is desirable to engage a rapidly deployable, scaleable, and transportable Wireless Wide Area Network (W-WAN) with multimedia (video, voice, data) capability. There are compelling commercial and military applications for this type of network. Although wireless alternatives exist, the alternatives possess less than desired performance:

- Cellular Digital Packet Data (CDPD): slow (19.2 kb/s) and expensive ($80 per MB).
- Legacy packet radios: Slower than CDPD.
- PCS: Preoccupied with narrow band voice channels.
- MMDS and LMDS: Preoccupied with one way video distribution, expensive base stations (>$250K).
- Wireless LAN: 200 m range, < 2 Mb/s.

The desired system possesses the following characteristics, for both commercial and military applications:

- Multimedia data rates, i.e. >10 Mb/s to each individual user.
- Range of coverage greater than 5 km from the network access point to the user terminal.
- Operation in an unlicensed frequency band for broad commercial appeal. Technology applicable to any frequency band.
- Connectivity to various network backbones (ATM, TI, or fast ethernet).
- Low cost implementation using Commercial-Off-The-Shelf (COTS), volume production elements, especially for the multiplicity of user terminals.
- Independence from the wireline infrastructure up to the network access point.
- Common, commercial network management software and applications.

For military applications, in particular, the following attributes are desirable:

- Anti-Jam (AJ), Low Probability of Intercept (LPI) transmissions, and Low Probability of Detection (LPD).
- Small, transportable access hub. Smaller, lighter user roaming nodes (IKs).
- Small antenna which minimizes/eliminates antenna mast, guy wires, wind loading, set up time, etc.
- Compatibility with robust transmission waveforms (i.e. frequency hopped spread spectrum), compatibility with other multiple access formats (i.e., Code Division Multiple Access (CDMA)).

An *Intelligent Access Hub* architecture is proposed which satisfies the attributes listed above. The network elements are substantially COTS based. The architecture leverages advances in high speed networking and wireless LAN technology, and has enormous commercial viability. However, essential elements of the network as proposed are currently unavailable. The proposed research is focused on the development of these essential elements.

1.2 Definition of Problem

Recent developments in networking technologies have very broad appeal for the purposes of multimedia connectivity in a geographic region via a Wide Area Network (WAN). A *Switched Virtual LAN* is a broadcast domain which unites any arbitrary group of remote LAN segments and is a very attractive solution for a private WAN. As Ethernet technology advances from 10 Mb/s to 100 Mb/s to Gb/s capabilities, the capability of the WAN is restricted by the inter-LAN wireline speed, or, for a *Wireless WAN*, the capacity of the wireless interface. A review of the wireline WAN, and the proven effectiveness of using Switched Virtual LANs, suggests how the capacity of a Wireless WAN may be increased.

A standard Ethernet LAN is a shared medium technology, wherein capacity is restricted by the limitations (bandwidth) of the medium. More users create more contention and collision, and data throughput decreases, even as offered data increases (figure 1.2.1). Notice that for this case of very short transmission delay relative to packet length (transmission delay / packet length ratio = 0.01) throughput is limited to 80% efficiency, and may be substantially less. Traditionally, In order to provide more data rate capacity to end users, multiport routers have been deployed. Each physical segment created by the router is treated as a logical subnet, and traffic between subnets is routed. Although the router eliminates the shared medium problem, traffic between subnets is subject to router processing and consequent delay.

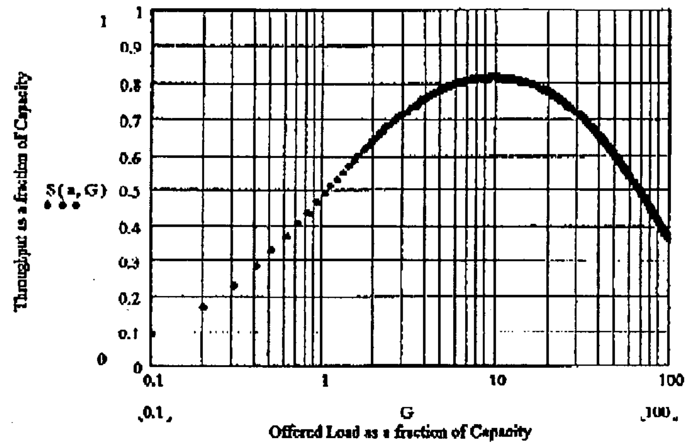

Figure 1.2.1 - Throughput (S) as a function of offered data (G),
a = Transmission Delay / Packet length = 0.01

Switched Ethernet is a solution to both problems (Figure 1.2.2). The Switched Ethernet reduces the shared medium problem by essentially allocating more medium. Users are individually allocated (or switched) a medium, rather than sharing the medium. The Ethernet switch caches Media Access Control (MAC) addresses, wherein a MAC address is associated with each user. Traffic is switched between users according to the port associated with each unique MAC address. The MAC address list contained in the Ethernet Switch defines the members of this *Virtual LAN*.

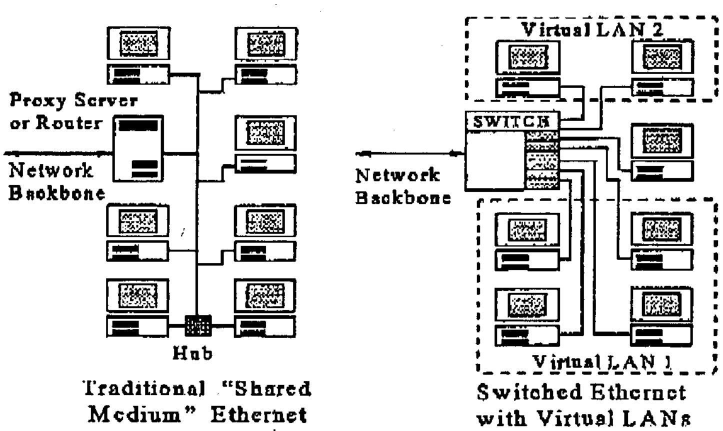

Figure 1.2.2 - Evolution from Ethernet to Switched Ethernet serving Virtual LANs

The Switched Ethernet also mitigates the router delay problem. Traffic is switched – rather than routed – within the Virtual LAN. LAN segmentation can be realized with Virtual LANs, rather than creation of a subnet for each segment. (The subnet requires a router, and associated routing delays). More Virtual LANs segments per subnet means

fewer routing delays. The Ethernet Switch which services the Virtual LAN is ported to a router or ATM LAN emulator for connection to the enterprise network backbone. Each Virtual LAN is uniquely identified by network management, and traffic between Virtual LANs is either routed or carried by the ATM backbone. There is a growing trend in industry towards Switched Ethernet and the utility of Virtual LANS.

In a Wireless WAN (W-WAN), user terminals share a common RF channel rather than a shared wire. Capacity is restricted by the radio interface to the Ethernet switch (the radio bridge), and ultimately, by the shared RF medium. Once again, the shared medium is the bottleneck, although now it is not the limited bandwidth of a wireline, but the limited allocation of frequency for the purpose at hand. Actually, the throughput problem is substantially aggravated for a wireless WAN, relative to a LAN, because of the longer transmission propagation delays. The longer transmission propagation delays create more collision opportunities, consequently requiring higher re-transmission rates. Figure 1.2.3 shows the impact on throughput as a function of offered data as the transmission propagation delay approaches the duration of a packet length. Notice that as transmission propagation delays become as long as a packet length in time (in this case, transmission delay / packet length ratio = 1), throughput as a percent of offered data can become very low.

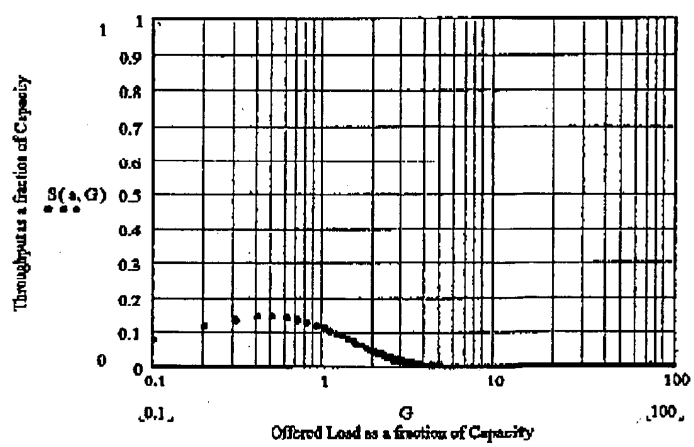

Figure 1.2.3 - Throughput (S) as a function of offered data (G),
a = Transmission Delay / Packet length = 1

It is thus critical to maximize the number of virtual LANs (switched, dedicated medium), and minimize the number of users per virtual LAN (shared medium) for a wireless WAN. With a wired network, this is achieved as described above; by using an Ethernet switch wherein each user is allocated a dedicated Ethernet port and line, rather than users sharing an Ethernet port. But how can this be done in the context of a wireless network, when all users share common RF channel?

Examination of legacy wireless technologies does not provide a solution. Analog cellular and PCS systems are limited by the shared medium problem. With these technologies Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), or Code Division Multiple Access (CDMA) is used to permit simultaneous users access to a limited bandwidth. Although historically adequate for narrow voice channels, even these systems are reaching capacity limitations using these multiple access techniques. Existing commercial wireless LAN products address the problem by keeping the transmission ranges low (up to a few hundred meters), thereby minimizing propagation delay, and by substantially reducing data rates (by contention and collision), as occurs in the traditional Ethernet. Thus, the wireless LANs generally provide less than 2 Mb/s data rates.

1.3 Description of the Solution

The proposed solution is to exploit the spatial filtering properties of directive antennas using an *Intelligent Access Hub* architecture. Figure 1.3.1 shows an example of the Intelligent Access Hub concept using eight planar multibeam antennas (dashed line pattern) for 360° coverage. Within the field of view of each multibeam antenna, directive beam patterns (solid pattern) emphasize the signal received from (or transmitted to) the desired Information Kiosk (IK) and de-emphasize interference from other directions. The figure shows five active directive beams. If interference is adequately suppressed, then spatially segregated IKs may simultaneously share the same frequency channel in a process called Spatial Division Multiple Access (SDMA).

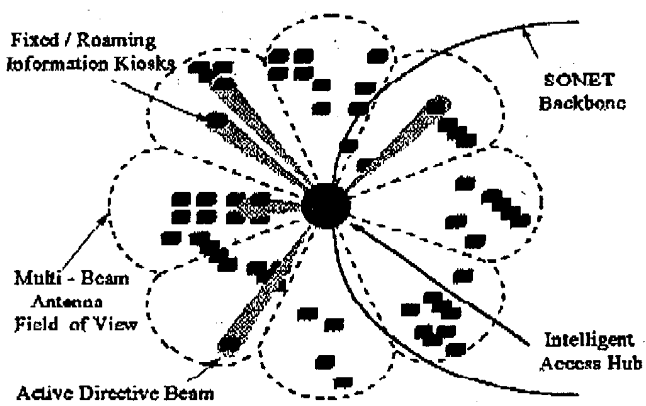

Figure 1.3.1- Intelligent Access Hub Service Area

With SDMA, directive antennas are used to provide the link from the Access Hub to the IK, with the full available RF spectrum provisioned to each port. Thus, each IK may be allocated a dedicated port at the Ethernet or ATM switch, rather than sharing the port with multiple IKs. (The analogy with the wireline case is the evolution from a single shared wire Ethernet, to the Switched Ethernet, wherein each user is allocated a dedicated wire and port). SDMA permits frequency reuse, wherein each IK uses the same RF

channel, and isolation is achieved by the spatial filtering of the antenna pattern. Just as the switched Ethernet wireline implementation permitted the user to achieve the full data rate of the Ethernet port, SDMA permits the IK engagement of the full allocated RF spectrum.

The Intelligent Access Hub is comprised of several multiple beamforming antennas. The multiple beamforming antennas are arranged to cover the geographical region of interest (In the figure, eight multiple beamforming antennas are used to cover 360°, fewer antennas may be used to cover only geographic regions desired). Within the multiple beamforming antenna field of view, the beamformer generates multiple, directive, spatially segregated beams to nominally service individual IKs. Each directive beam is associated with a COTS radio bridge, which is ported to a COTS Ethernet Switch (Figure 1.3.2). The Ethernet Switch is served by a COTS ATM / LAN emulator for connection to the ATM backbone, or by a router for connection to the enterprise LAN or TI. The number of radio bridges required in the Access Hub is the product of the number of multiple beam antennas and the number of directive beams per antenna. There are now low cost 10 Mb/s radio bridges available, which makes the multiplicity of radio bridges in the Access Hub economically acceptable. The Intelligent Access Hub may be served by a single Ethernet Switch and ATM LAN emulator.

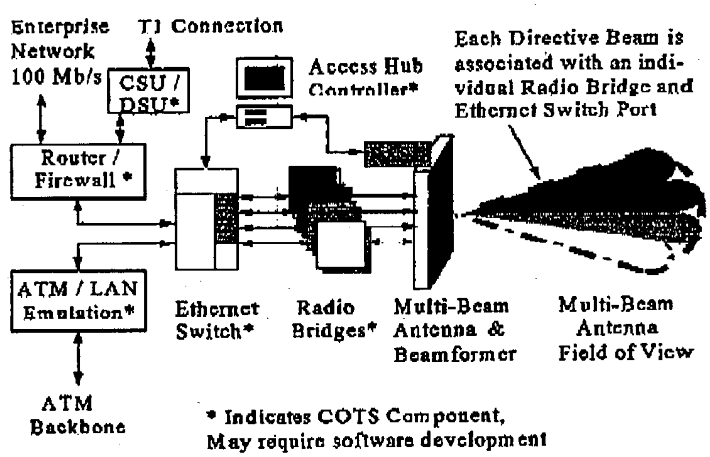

Figure 1.3.2 - Intelligent Access Hub Components

The Intelligent Access Hub serves IKs either line of sight (LOS) or through relays. The IK is comprised of a low cost fixed antenna, Received Signal Strength Indicator (RSSI), low cost COTS radio bridge, and local access terminal and controller (Figure 1.3.3). The COTS radio bridge being considered is a $600 (in low volume) ISA card which provides a gateway between the Ethernet and the 10 Mb/s radio environment, providing for a low cost transceiver (<$1000 with radio bridge, fixed antenna, and software). Note that this is the same radio bridge used in the Access Hub. The local access terminal may be the final user terminal or may be ported to an Ethernet switch to provide the options for ATM / LAN emulation, routing to a local subnet, or connection to a legacy mobile switching center.

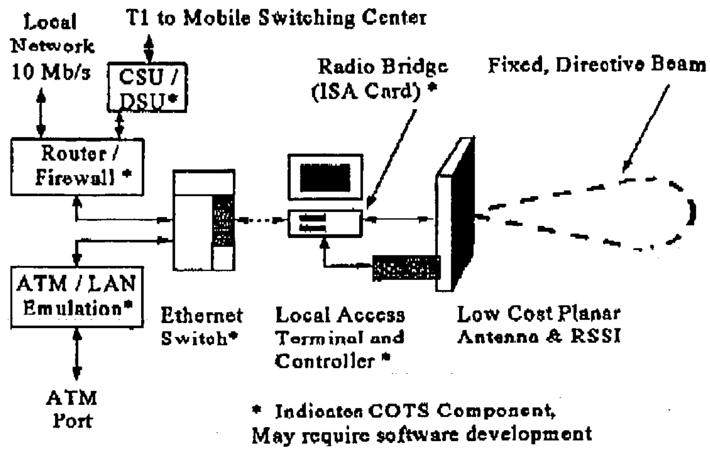

Figure 1.3.3 - Information Kiosk Components

Individual IKs are identified by their MAC address, and roaming IKs may be accommodated by adaptively updating the MAC address list within the Ethernet switch and engaging the appropriate directive beam. Alignment of directive antennas is critical but is quickly achieved with available software. The IKs serve as 10 Mb/s network access points for legacy wireless or wireline LANs, data, or voice systems.

The requirements for an effective SDMA system are similar to the requirements for Anti-Jam (AJ), and Low Probability of Intercept/Detection (LPI/D). The Hub Directive Antenna architecture requires that 1) Interference from outside of the intended narrow beam is minimized, 2) minimum power is transmitted for acceptable Signal to Interference Ratio (SIR), 3) Transmission only occurs when data is present, 4) sidelobes are as low as possible. These properties are advantageous for either AJ, LPI/D or both.

The intention of the Intelligent Access Hub architecture is to leverage the multiplicity of low cost networking applications available commercially, and to simply provide the 10 Mb/s pipeline from the Access Hub to the IK to effectively utilize these networking applications. The Intelligent Access Hub concept is applicable to many communication mediums, but for the purposes of this SBIR, an Ethernet bridge is proposed for the following reasons: 1) the COTS radio bridge, used individually in the IK and in multiplicity at the Access Hub, is inexpensive, 2) the network terminals (PCs) and applications are inexpensive and ubiquitous, 3) There are numerous, and ever increasing, COTS applications which have particular commercial appeal (i.e. IP telephony, Videoconferencing, etc.), 4) It is easily ported to other network backbones (i.e. ATM backbone via COTS LAN emulation, TI through router and CSU/DSU).

Note that the Intelligent Access Hub network, other than the smart beamforming directive antenna, is COTS based. The Ethernet switch, Virtual LAN technology, Router or ATM LAN emulator, and radio bridge are very high volume, robust commercial products.

Additionally, the capabilities of these products (in terms of data rate / $) increases dramatically every year. The prospect of providing wireless WAN networking services, particularly in an unlicensed band, has immense commercial appeal. In order for an effective Wireless WAN to be deployed, the intelligent directive antenna technology *must* be developed which maintains pace with rapid increases in Virtual LAN, ATM backbone, and point to point radio bridge technology.

The number of simultaneous co-channel IKs serviced by the Access Hub is determined by the ability of the radio bridges to perform effectively in the presence of co-channel interferers. It is desirable to engage a beamformer with a very large number of independent beams which could, through spatial filtering, provide the full RF bandwidth to a very large number of IKs at great range. However, increasing the number of IKs increases interference potential, and restricts the throughput and capacity of the system. Thus the system is Signal to Interference Ratio (SIR) limited. The research to be performed is analysis of the sources of co-channel interference, development of effective means of reducing interference, and optimization of capacity of the Intelligent Access Hub.

2. Phase I Technical Objectives

Highly valuable military and commercial applications for the Intelligent Access Hub exist, but there are no current implementations due to a void in multiple beam directive antennas and radio bridges adapted for this application. The advantage of the architecture has been described. The special requirement is to provide spatial filtering, requiring multiple beam directive antennas with isolation between beams. However, even with multiple beam antennas, adjacent beam interference will be high. Development of an Intelligent Access Hub is required which adapts transmission power and radio bridge transmission protocol to the real time set of operating conditions. Performance of the radio bridge in the presence of interference must be quantified to determine adjacent beam isolation and power control requirements. The Phase I research to be performed has the following objectives:

1. How many individual IKs may be serviced simultaneously? What is the required spatial separation for individual 10 Mb/s data rates? What is the range of coverage?
   - Analysis of the requirements for the Multiple Beam Directive Antenna.

2. In addition to spatial filtering provided by antennas, what other provisions must be made to mitigate co-channel interference?
   - Specification of the requirements for adaptive power control.

3. Even with spatial filtering and adaptive power control, co-channel interference is anticipated. How will the radio bridge respond in the presence of interference?
   - Analysis of the performance in the presence of interference.

4. In the event that individual IKs may not be spatially resolved, how is service multiplexed?
   - Generation of the algorithm for multiple IKs in a single beam.

5. Preparation and submittal of Phase I final report.

3. Phase I Work Plan

Resolution of issues described in Technical Objectives is achieved per the schedule of the work plan. The deliverables consist of a detailed report on the research analysis and conclusion of each of the topics discussed in Technical Objectives.

3.1 Performance Schedule

1. Analysis of the requirements for the multiple beam directive antenna.
   - Will be completed two months after work begins.

2. Specification of the Intelligent Access Hub adaptive power control.
   - Will be completed three months after work begins.

3. Analysis of the radio bridge performance in the presence of interference.
   - Will be completed three months after work begins.

4. Generation of the algorithm for multiple IKs in a single beam.
   - Will be completed six months after work begins.

5. Preparation and submittal of Phase I final report.
   - Will be completed six months after work begins.

3.2 Multiple Beam Directive Antenna

3.2.1 General Description

The multibeam antenna function within the Intelligent Access Hub function is shown in figure 3.2.1. It is comprised of an N X N hybrid matrix which feeds N radiating elements from N I/O ports. Each of the I/O ports is associated with an individual radio bridge and radiated beam. The Access Hub contains a Received Signal Strength Indicator (RSSI) which provides information on the signal strength received from each beam. Each I/O port (and consequently, each beam) has a voltage variable attenuator to adaptively control radiated power. In order to create the multiple directive antenna beams, a passive, lossless N X N Butler Matrix is to be developed. Lossless in this context means there is no amplitude tapering of signal amplitude to radiating elements. This matrix will be developed for U-NII band operation, but the technology is applicable to other frequency bands.

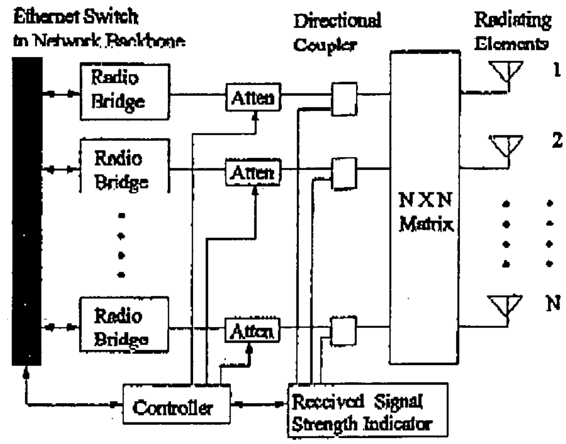

Figure 3.2.1 - Multibeam Antenna

3.2.2 Antenna Beam Crossover Level

The number of antenna beams and their respective beam widths is determined by the hybrid matrix. The hybrid matrix is an N X N Butler Matrix configuration, wherein there are N radiating antenna elements, N fixed directional beams, and N I/O ports, each uniquely associated with an antenna beam. Figure 3.2.2.1 shows a 4 port example. For this multiple beam system it is desirable to have high gain and low sidelobe levels. In addition, it is desirable to have a fairly high *beam crossover level* (BCL-as shown in figure 3.2.2.1) so that nearly the full system gain is available to all positions within the antenna field of view. The beam crossover level is defined as the ratio of the antenna gain at the angular position of adjacent beam crossover, relative to the gain at beam boresight.

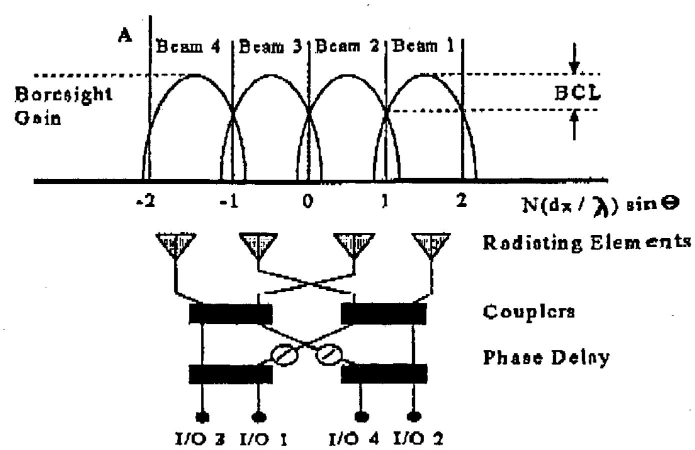

Figure 3.2.2.1 Butler Matrix and Beam Crossover Level

Presuming that Spatial Division Multiple Access (SDMA) is to be fully exploited, it is desirable that even adjacent beams radiated from the Access Hub share the same RF channel, i.e. all beams share the same full RF bandwidth. The constraint is co-channel, cross beam interference, wherein the signal from (or to) the desired IK is interfered with by the signal from (or to) other IKs. The cross beam interference is largely determined by the Beam Crossover Level.

As noted, it is desirable to maintain a high beam crossover level to provide high antenna gain to all azimuthal positions within the antenna field of view. The drawback is reduced isolation between sectors. For example, if the Beam Crossover Level is 4 dB, then all points within the antenna field of view have gain within 4 dB of the maximum antenna gain, but the isolation between adjacent sectors is low. Limitations of the spatial filtering concept are defined by the interference from adjacent beams and from the sidelobes of non-adjacent beams.

The beamformer hybrid matrix feeds the radiating elements in phase progression, depending on the input port which is stimulated. The hybrid matrix is designed such that each input port has a uniquely associated beam radiation pattern. It can be shown that for a lossless hybrid matrix (which is desired to maintain system gain) only uniform amplitude element stimulation may be achieved [1]. Thus, with this type of feed, amplitude tapering of element feeds is not possible, and sidelobe levels will be fairly high (~13 dB). It can also be shown that for a passive, lossless, matrix beamformer, the array space factor will be orthogonal, meaning that the beams may not be arbitrarily scanned, but rather will be fixed in space [2]. For the Intelligent Access Hub architecture this requires that all potentially usable beams must be ported to an individual radio bridge, whether that beam is immediately engaged or not. Methods of reducing sidelobe levels and for providing arbitrarily scanned beams are discussed in the section on future research.

The Butler Matrix is the analog implementation of the Fast Fourier Transform, thus requires N(log N) signal combinations to excite N beams for an N element array from N input ports. The Butler matrix is realized as a set of couplers which provide phase progression to radiating elements. The beam maxima are located at angles designated as θ_p for the *m*th beam

$$\sin\theta_p = (\lambda/N\, d_x)(N + M - 1/2)$$

Where λ is the wavelength, d_x is element spacing, and N is the number of elements. The phase progression between elements is given by

$$\delta = (2m\pi / N)$$

and the angular sector θ' covered by the multiple beams is approximated by

$$\sin\theta' \approx 2 \sin^{-1} (\lambda/2\, d_x)$$

Thus, for a large array, the multiple beam antenna field of view is determined by only the element spacing and the wavelength. The number of beams in the field of view, and the individual beamwidth, is determined by the number of radiating elements.

Generally, element spacing is dictated by 1) the requirement not to space elements greater than $\lambda/2$ apart to avoid grating lobes, and 2) the requirement to space radiating elements as far apart as possible to avoid mutual coupling. For large arrays the Beam Crossover Level is 3.92 dB for the $\lambda/2$ element spacing. Using this value as a starting point, analysis will be performed on interference levels between beams and the requirements for Adaptive Power Control. Element spacing will be iteratively optimized following analysis with Adaptive Power Control.

Multiplicity of beams ultimately determines the maximum capacity of the Hub Directive Antenna architecture. Clearly, more beams could service more users, but only up to a certain point. The increased interference levels caused by the increased number of beams, and their associated sidelobe level, will ultimately limit system capacity, so the system is SIR limited. As noted above, the larger the number of beams, the longer the array, and more elements and I/O ports to be engaged. Thus, the physical realization of a very large number of beams becomes problematic. Analysis will focus on reasonable estimates of IK proximity and utilization wherein adjacent beam and non-adjacent beam side lobe interference will be presumed. Optimum number of beams per multiple beam antenna shall be ascertained from this analysis. Directivity and 3 dB beamwidth shall be determined which consequently determines range of coverage and spatial resolution between IKs.

Another factor to be investigated shall be the angular field of view of the multiple beam antenna. Generally for uniform linear arrays, it is (theoretically) possible to steer the antenna from endfire to broadside radiation. For microstrip patch resonator antennas, high angle from broadside radiation is very inefficient because of the low element gain at high angles. Thus the multiple beam antenna should have a field of view of substantially less than π radians. Analysis shall be performed on optimizing field of view gain for the multiple beam antenna.

The matrix beamformer itself is realized as passive couplers and delay lines etched on a board. The cost of this technology is low relative to some of the other system elements, and is not expected to be the major cost driver. The matrix beamformer may be integrated with the radiating elements in a low loss, low parasitic, multilayer microwave subassembly. An estimate of the cost and size of this assembly will be generated by this research.

[1]. Shelton, J.P. et al "Multiple Beams from Linear Arrays", IRE Transactions on Antenna and Propagation, March 1961, page 154.

[2] Allen. J.L. "A theoretical Limitation on the Formation of Lossless Multiple Beams in Linear Arrays". IRE Transactions on Antennas and Propagation 9, page 350

3.2.3 Worst case scenario

The worst case scenario is shown in figure 3.2.3.1. In this case, IK A, which resides at the azimuthal position corresponding to the beam crossover level, is to be serviced by radio Bridge A (RB A) via beam A. Beam B from RB B interferes with Beam A. It is presumed for the moment that IK A and B are equidistant from the Access Hub, and that the propagation loss to each is the same.

For the downstream transmission case, i.e. the Access Hub radio bridges transmitting to the IKs, IK A nominally receives equal power from beam A and B (solid beam pattern in figure 3.2.3.1). Thus, to simultaneously engage IK A and B, the power from RB B shall be reduced to Beam B' (dashed line in figure 3.2.3.1) so that IK A receives the strongest signal level from RB A. Note that because of the high gain of beam B at IK B, the signal at IK B is still dominated by beam B.

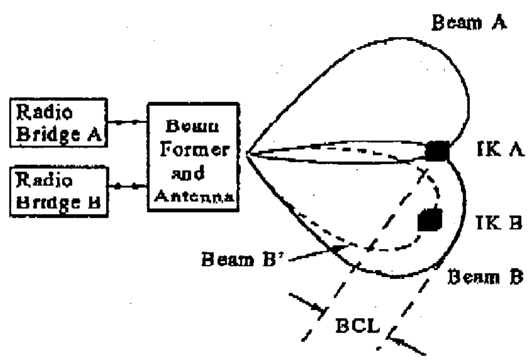

Figure 3.2.3.1 - Case of Interference with IK A at beam crossover

For the upstream transmission case, i.e. where both IK A and B are transmitting to the access hub, RB B receives signal from both IK A and B. The signal from IK A is suppressed only by the beam crossover level, or less if IK B is not located at the beam boresight. Thus, the transmit power from IK A shall be adaptively reduced to provide the minimum acceptable SIR at RB A.

It is possible to obtain a higher isolation between beams by using a very low beam crossover level, i.e. the beam crossover level gain is very low relative to boresight gain. However, very low gain positions within the antenna field of view will inevitably and unacceptably drop-out IKs. Thus a high beam crossover level shall be maintained. Resolution of the interference problem is achieved by Adaptive Power Control as described in the next section.

3.3 Adaptive power Control

In general, it is desirable to transmit (in either direction) the lowest power which provides the required signal to noise ratio (SNR) and fade margin. This enhances the capacity of SDMA and reduces probability of intercept and overall interference levels. Thus, it is necessary to construct *adaptive power control* for both the Access Hub and IKs. The adaptive power control function is able to sense the received signal level, and command the transmitting source to increase or decrease accordingly.

3.3.1 Adaptive Power Control Implementation

The COTs radio bridge equipment transmits a fixed power level. Therefore, power control is performed using a variable attenuator at the radio bridge input/output. The variable attenuator may be incorporated as part of the passive beamformer and does not require modification of the COTs radio bridge. Additionally, a Received Signal Strength Indicator (RSSI) is provided at the I/O port of the radio bridge in the Access Hub. Network management algorithms within the Access Hub controller provide the adaptive power control. Upon initial engagement of an Access Hub to IK link, the IK senses the power level received and, presuming that the Access Hub initially transmits the maximum permissible power, estimates the range based on the received power level. The IK then transmits at an adapted power level which will provide the minimum SNR plus fade margin at the Access Hub. The initial packets transmitted are management packets which contain information on received signal level. The IK provides information to the Access Hub on received signal power and the Access Hub consequently adapts its transmitted power to provide the minimum acceptable Signal to Noise Ratio (SNR) plus fade margin to the IK. Using this method, each link transmits minimal power to mitigate interference to other beams, and reduce overall probability of intercept.

Since the Intelligent Access Hub architecture is an SDMA system, it is Signal to Interference ratio limited (SIR), rather than SNR limited. Thus, the power adaptation must be exercised in the presence of multiple co-channel interferers. However, since all transmissions are presumed to be to or from the Access Hub, it is possible to compute the expected interference level, and adapt the transmission power appropriately.

Investigation of requirements for the Adaptive Power Control shall be performed. Analysis of Adaptive Power Control as a function of co-channel interference, Beam Crossover Level, and capacity shall be performed. Specifications shall be developed for the realization of the Adaptive Power Control algorithms and RSSI circuitry. Requirements of the power management packet shall be defined.

3.4 Performance in the Presence of Interference

Upon reception of the transmitted signal the radio bridge (at both the Access Hub and IK) de-modulates the RF carrier in the presence of interference. The radio bridge employs FSK modulation format, a class of frequency modulation. An integrated digital

demodulator performs carrier frequency acquisition and tracking and symbol timing. When co-channel interference of two signals having nearly equal amplitudes occurs at the demodulator, the stronger of the two signals tends to dominate the de-modulation process, displacing the other signal entirely. This effect is called the *Capture Effect.*

3.4.1 Analysis of Carrier Capture Effect

Although it appears to be a panacea for mitigating co-channel interference, the fluctuating signal amplitudes of the desired signal due to multipath fading may cause the undesired signal to dominate occasionally. Thus, fade margin is required, and a quantification of the capture effect for the specific de-modulator used is required. Analysis is to be performed to determine the SIR required to exploit the capture effect for radio transmission in the presence of strong co-channel interferers. ANNTron, Inc. shall procure radio bridges for the purpose of evaluating and quantifying the performance of the radio bridge in the presence of interference.

3.4.2 Fade Margin

Exploitation of the carrier capture effect requires determination of effective fade margin for the radio bridge in question. Analyses will be performed on the fade margin required for this directive antenna WAN application. Note that fading is not expected to be as dramatic for this application relative to long distance terrestrial microwave links, nor as severe as for mobile systems served by omnidirectional radiators.

3.5 Multiple IKs in a Single Beam

The multiple beam directive antenna will have beams fixed in space. Nominally, each beam will service a single IK. There will be situations when closely located IKs, or IKs which are radially distant but subtend a small angular spacing, may only be serviced by a single beam. In this case the beam and associated radio bridge must multiplex two (or more) IKs. Data throughput will be reduced, as now the transmission medium is shared. However, a multiple access scheme used by existing wireless LANs shall be specified to efficiently support multiple co-beam IKs.

3.5.1 Multiple User Algorithms

Presently, most of the radio bridging equipment does not provision for multiple access because the bridge is intended to service a single point to point link. Software drivers for the radio protocol ASIC will be specified which will permit multiple access through the radio bridge. This protocol shall be based on the common Collision Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol used in the IEEE 802.11 specification for wireless LANs. CSMA/CA uses a carrier sensing capability to prevent a node from transmitting will another node is transmitting. When no carrier is sensed, the node waits a short, random period before transmitting. If a collision occurs, re-transmission is delayed a short random period. Analyses shall be performed on reduction of data throughput for the case of multiple IKs in a single beam.

3.6 *Final Report*

A final report shall be generated which provides detailed explanation of the research approach, analyses, results and conclusions. Adequate information to provide the basis for generation of field prototype shall included in the final report.

4. Related Work

ANNTron is a small business engaged in systems engineering design and development for the telecommunications industry. The company is focused on high capacity wireless access to network backbones. The long term objective of ANNTron is to develop products derived from these system design efforts, and to sell these products in the commercial market.

The principal investigator recently completed design and analyses of a Local Multipoint Distribution Service (LMDS) duplex data network to service a small city. This work was done for a corporation which provides Internet Service and microwave video links. This work was detailed adequately to generate requirements for the microwave transceiver, antenna, and modem interface, based on service, data throughput, and capacity requirements. This work was completed in March 1998.

This work was largely focused on providing the capability for duplex high data rate microwave transmission from a head end to a multiplicity of high capacity remote nodes. Detailed analyses revealed the limitations in using low gain (omnidirectional antennas) for this application. The low gain antennas require high power transmitters, which, at the LMDS frequency, are very expensive. Additionally, the high data rate system requires very high linearity performance in the transmitters. Improved linearity is generally achieved by "backing-off" or reducing transmitter power, however, this consequently reduces range of coverage dramatically. Lower power transmitters, or much higher data rates, may be achieved by using fixed, high gain, directive antennas. However, the fixed antennas are not compatible with a rapidly deployable, convenient system. Each fixed antenna requires professional installation, and a tower or mast for positioning. Changes in remote node position or service requirements mandate expensive modifications to the antenna and supporting tower or mast.

A portion of this LMDS work was performed jointly with the Center for Information and Communications Technology Research (CICTR), a laboratory within the Electrical Engineering College of the Pennsylvania State University. It is proposed that a portion of the Phase I effort shall be subcontracted to CICTR. Currently, CICTR is involved in research and development in the areas of Broadband Network Access Systems, Local Wireless Communications, Wireless Multimedia (including mobile computing), Personal Mobile Communications Systems, and Information and Communication Theory.

5. Future Research

The Phase I investigation shall verify the Intelligent Access Hub concept utility for Wireless WANs, and answer the fundamental questions concerning throughput, capacity, range, and cost. This investigation will provide the foundation for the detailed specification of an Intelligent Access Hub. The Phase I Option will aggregate the conclusions into a detailed specification for a prototype. Phase II follow up will be the design and demonstration of the functionality of the beamformer and antenna, power adaptation, and multi-user protocol radio bridge, and demonstration of field prototype. It is expected that significant commercial interest will be generated by the demonstration of the prototype, which will sustain future research.

This analysis will also benchmark the hybrid matrix multi-beam antenna technology. Theoretically, a much higher performance system may be realized using digital beam forming techniques. The digital beam former provides truly arbitrarily directed beams with much lower sidelobe levels. Thus, the SIR may be much lower, and consequently, data rates and capacity much higher. At this time, the digital beam forming technique is considered a high risk approach on the basis of 1) very high computational and sampling rates required of the digital signal processor, and 2) a void in COTs components which will support this technology. Clearly, as signal processor rates increase, this technique should be explored further.

The analysis performed on the Intelligent Access Hub, in terms of required SIR to support data rate and capacity, is applicable to the digitally beamformed smart antenna technology. And may be the basis for advanced, very high capacity networks in the future.

6. Commercialization Strategy

As of 1997, 25 million Ethernet nodes had been sold and the growth rate is 30% per year. Worldwide wireless LAN sales are expected to increase from $500 million in 1997 to over $2 billion in 2000, a very dramatic growth rate. Clearly, extending the physical reach of LANs to WANs will accelerate this growth curve. The public data network carriers are the biggest purchasers of WAN equipment. In 1996 they accounted for 36% of WAN equipment purchases. With the rise of the Internet, public data network carriers are predicted to account for 51% of WAN equipment in 2000. The general trend is for frame relay and ATM providers to offer WAN management services. Other purchasers are individual companies with high speed connectivity requirements, Internet Service Providers (ISPs), and private systems. As the requirements for multimedia access grow, sales of multimedia wireless WAN equipment will start with competitive service carriers and will ultimately complement the public data network carriers infrastructure.

An unlicensed wireless medium for high capacity transport is attractive to all companies involved in multimedia WANs. The medium is particularly attractive to Competitive Local Exchange Carriers (CLECs) because of the scaleable infrastructure build-out costs and

rapid installation. The medium is attractive to ISPs whose costs and services are substantially driven by the Incumbent Local Exchange Carriers (ILEC) line lease rates. It is also attractive to Businesses, schools and other institutions which cannot justify the line lease fees. Currently, service for multimedia applications is very limited. An entity desiring to connect to a backbone WAN generally is limited to requesting and paying for service from the ILEC, including installation and monthly line lease. The options include T1, Frame Relay, ADSL or cable modem service. For many services, the line lease fees and installation costs are prohibitive. The wireless WAN provides an economical alternative to paying monopolistic line lease fees.

The wireless WAN will be targeted to CLECs and ISPs which will be able to justify, using this technology, providing enhanced services such as file management and backup services, interactive website management, videoconferencing, IP telephony, and virtual LAN management. Military applications include high capacity, rapidly deployable field networks, and backbone networks in support of legacy wireline and wireless voice and data systems. Field applications include disaster relief zones and urban warfare zones where dependence on wireline infrastructure is precluded.

The Intelligent Access Hub is comprised substantially of COTS elements, including the radio bridge, Ethernet or ATM switch, and network management. The proprietary components are the Antenna, beamformer, and algorithms for adaptive power control and multiple access. ANNTron, Inc. will design and develop these elements, and integrate turn-key wireless WANs for commercial applications.

7. Key Personnel

7.1 Principal Investigator - Scott Thompson

Mr. Thompsons' most recent work for ANNTron, Inc. is in the specification for a wireless WAN using smart antennas and digital beamforming techniques for very high data rates. This is for a prospective government agency which is currently deploying a high capacity ATM network in a metropolitan area.

Prior to this activity Mr. Thompson designed a Local Multipoint Distribution Service (LMDS) duplex data network to service a small city. This work was done for a company which provides Internet service and microwave video links. Service, data throughput, and capacity requirements were analyzed. From this analysis, requirements for antennas, transceivers, and the modem were identified and specified.

A portion of this work was performed jointly with the Center for Information and Communications Technology Research (CICTR), a laboratory within the Electrical Engineering College of the Pennsylvania State University. Mr. Thompson was responsible for creating technical requirements for research topics and providing assistance to researchers.

Mr. Thompson has 17 years of experience in the electronics industry. In his previous position, Mr. Thompson was responsible for the design, development, and production test and manufacture of the microwave front end for vehicular collision avoidance radar. This included the design of a low cost, multilayer microwave antenna and feed network.

Mr. Thompsons' experience areas are in telecommunications, systems integration and verification, microwave microelectronics, and military microelectronic modules for radar/sensor applications. Mr. Thompson has worked at Texas Instruments and the HE Microwave subsidiary of Hughes. Mr. Thompson has a B.S.E.E. from the Pennsylvania State University (1981) and an M.S.E.E. from Southern Methodist University (1985).

7.2 Fred C. Thompson - Corporate Officer

Mr. F. Thompson is the President and Founder of ANNTron, Inc. and will participate in systems engineering design efforts on this proposal. Mr. F. Thompson has a B.S.E.E. and M.S.E.E. degrees from the Pennsylvania State University and has career experience in the wireless industry. Mr. F. Thompson is a registered Professional Engineer in the State of Pennsylvania.

7.3 Dr. Mohsen Kavehrad - Sub-Contracted through CICTR

Dr. Kavehrad is the W.L. Weiss Endowed Chair Professor of Electrical Engineering at the Pennsylvania State University. He is the director of the Center for Communication and Information Technology Research (CICTR) in the Electrical Engineering Department of the Pennsylvania State University. Dr. Kavehrad holds the B.Sc. degree in Electronics from the Tehran Polytechnic Institute, Iran, the M.Sc. degree from Worcester Polytechnic Institute, Massachusetts, and the Ph.D. degree from Polytechnic University, Brooklyn, NY.

Dr. Kavehrad has published close to 200 papers and holds several issued patents in the telecommunications field. He is a Fellow of the IEEE for his contributions to Digital Wireless Communications. He has worked at Fairchild Industries, GTE Satellite Corp. and Laboratories, and AT&T Bell Laboratories.

8. Facilities/Equipment

8.1 Company Information

ANNTron, is incorporated in Pennsylvania. ANNTrons' business area is in the development of technologies for future high capacity wireless networks with particular emphasis on using smart antenna technologies to keep pace with multimedia Ethernet and ATM hardwired networks. ANNTron is using the extensive electronics industry experience of its employees to design cost effective solutions for new markets being created by wireless networking technologies. The investigation for Phase I shall be

performed at ANNTron using PC based mathematical and antenna modeling tools which ANNTron owns to simulate system performance.

ANNTron will purchase radio bridges for Phase I for the purposes of executing Task 3.4, Performance in the Presence of Interference. ANNTron, Inc. is planning to enter into an Intellectual Property Partnership Program with the OEM for the radio bridge which has been identified for this application. This will permit ANNTron to have access to the radio bridge Intellectual Property (source code and specifications) in order to make modifications to the radio bridge drivers for multiple access operation.

The resources of the Center for Information and Communication Technology Research (CICTR), College of Electrical Engineering, Pennsylvania State University, will be employed for optimization of multiple access protocols and evaluation of the radio bridge in the presence interference. CICTR owns SPW, EESof system IV, Omnisys, and MATLAB software tools for system analysis. CICTR also owns test equipment, including microwave signal generators, spectrum analyzers, and power meters, for radio bridge evaluation.

9. Sub-Contract

A portion of this work, as costed in Appendix C, shall be sub-contracted to the Center for Communication and Information Technology Research (CICTR), College of Electrical Engineering, Pennsylvania State University. The Director of the CICTR is Dr. Mohsen Kavehrad. The goal of the CICTR is to team with industrial partners to generate solutions to current and future technical challenges in the transmission, storage, transformation, and networking of digital information (The CICTR website is: http://cictr.ee.psu.edu/).

CICTR will be specifically sub-contracted to perform the subtask described in section 3.5, Multiple IKs in a Single Beam. CICTR will also be subcontracted to perform a portion of the evaluation of the radio bridge in the presence of interference as described in section 3.4. It is planned that, in the event a Phase II proposal is solicited, CICTR will be subcontracted to perform additional developmental work on the field prototype Intelligent Access Hub. This additional work is planned to be in optimization of ATM throughput.

10. Similar Proposals and Awards

No prior, current, or pending support for proposed work.